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Selectivity in the Study of the Cardiovascular System

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• The principle of selectivity in the roentgenology of the cardiovascular system is now firmly established. The chambers of the heart and certain vascular beds lend themselves admirably to selective catheter or needle study, without the necessity of perfusing large segments of the cardiovascular bed which are irrelevant to a particular study.

A technique of percutaneous transfemoral selective *ciné* coronary arteriography has been developed and applied to clinical subjects. Nevertheless, selectivity has specific limitations, and the use of the selective versus the nonselective approach must be weighed in each case, with the status of the patient as well as the requirements of the diagnostic investigation taken into account in reaching a decision.

TRULY SELECTIVE DEPOSITION of contrast material in the study of the cardiovascular system cannot be construed as a development of the recent past. As early as 1923, Berberich and Hirsch,[4] using 20 per cent strontium bromide, reported the first arteriograms and venograms obtained in man by injection of a contrast agent directly into the venous or arterial bed under investigation. In 1928, Moniz[11] reported the successful study of the cerebral circulation by direct puncture of the carotid artery. Dos Santos,[18] in 1929, obtained satisfactory opacification of the abdominal aorta and its branches using translumbar needle puncture and injection. Two years later, Moniz[10] and his colleagues described the technique of "angiopneumography," as they called it, and employed Forssmann's method of heart catheterization to inject a contrast agent for the demonstration of the pulmonary vessels.

Nevertheless, in 1937 and 1938, when Castellanos and his coworkers[6] and Robb and Steinberg[16] independently described the technique of angiocardiography, their method was essentially nonselective in character. It involved the intravenous injection of a large volume of contrast agent, which mixed with the venous blood and flowed to the heart and great vessels, opacifying all chambers and both of the great vessels in orderly sequence. It was not until 1946, when Chavez[7] and his coworkers published their studies on intracardiac angiocardiography, that the selective method was first successfully applied to the study of the interior of the heart and great vessels in man. Jönsson and coworkers[9] utilized the method of Chavez extensively in the late '40s and early '50s and demonstrated the advantages of "selective" angiocardiography in defining morphologic and functional derangements of the heart with greater clarity and precision.

That this was also possible in the great arterial trunks had been demonstrated by Radner[14] in 1948

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when he described a method of thoracic aortography by catheterization from the radial artery.

The study of the visceral branches of the aorta was accelerated by Seldinger's description in 1953 of a technique of percutaneous puncture for catheter arteriography which was simple, efficacious, and did not involve an open surgical field.[19] The design by Ödman[13] of a radiopaque polyethylene catheter which could also be inserted percutaneously gave further impetus to contrast studies of the arterial system in vivo.

Within the scope of this paper, it seems desirable to summarize the present status of selectivity as it applies to a number of specific segments of the cardiovascular system.

1. *The Right Heart Chamber.* Selective study of the right atrium and right ventricle is readily accomplished by the passage of a catheter from a vein in the antecubital fossa, or from the saphenous or femoral vein. This can be done by using a cutdown and employing such catheters as the Rodriguez-Alvarez closed-end woven type with side holes, or by using percutaneous puncture and the radiopaque Ödman catheter with end and side holes. The visualization of the tricuspid valve area, the right ventricular outflow tract, the pulmonary valve and right to left shunts at the atrial or ventricular level is best accomplished by the selective approach. Selective angiocardiography should always be coupled with the acquisition of physiologic data—blood oxygens, pressures, dye curves—as a part of an investigation designed to obtain all possible morphologic and functional information about the problem.

2. *The Pulmonary Artery and its Branches.* The intravenous technique or injection with the catheter in the superior vena cava or right atrium for the study of the pulmonary vessels is usually quite satisfactory. Furthermore, when the objective of the study is to determine the effect of such lesions as carcinoma of the lung on the pulmonary vessels, then it is desirable to demonstrate the superior vena cava as well, in order to be certain that there is no evidence of invasion or partial occlusion of this great vein by the neoplasm. But the most exact study of the pulmonary artery and its branches is accomplished by placing the catheter in the main pulmonary artery or in one of its right or left main branches. This is an ideal approach to the study of pulmonary arteriovenous fistula, or of anomalous pulmonary venous return.

When detailed study of the small pulmonary arterial radicals is desired, the open end catheter may be placed in the "wedge" position and a small volume of contrast agent (3 cc.) injected by hand. This technique permits excellent definition of the changes in the character of the small vessels associated with pulmonary hypertension.

3. *The Left Atrium and Left Ventricle.* In many young patients, it is possible to catheterize the left atrium by passing the catheter from the right atrium through the foramen ovale into the left side of the heart. This is best accomplished with the catheter inserted from the inferior rather than the superior vena cava. In this way, it is possible selectively to opacify not only the left atrium, but also the pulmonary veins (Figure 1). Obviously, if there is a large atrial or ventricular septal defect, the catheter may pass readily across the septum into the left side of the heart. In patients with a large left to right shunt at the atrial level, it may be difficult to detect an associated ventricular septal defect by oxygen studies alone. It is important in these cases to determine the presence of an atrioventricular canal defect, and this is best accomplished by selective

Figure 1.—Selective pulmonary venography. (*Left*) Anteroposterior projection. (*Right*) Lateral projection. A catheter has been passed from the inferior vena cava into the right atrium and through the foramen ovale into the left atrium. The mouth of the catheter lies in the left upper lobe pulmonary vein, the branches of which are demonstrated by retrograde injection. A small amount of the contrast agent is seen in the body of the left atrium.

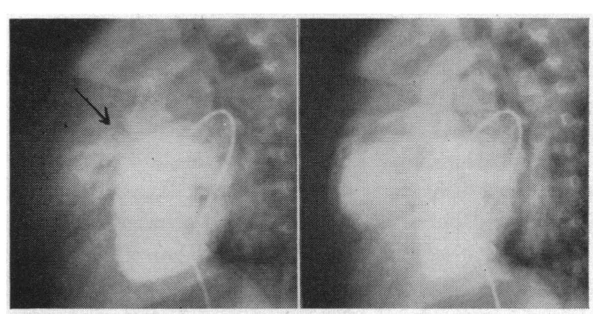

Figure 2.—Left ventricular injection in a ventricular septal defect with left to right shunt. The catheter has been passed from the inferior vena cava into the right atrium, through an atrial septal defect into the left atrium and finally through the mitral valve into the left ventricle. (*Left*) Left anterior oblique projection, one-half second after injection. The left ventricle is filled with contrast agent, and aortic filling is also visible. The contrast agent passes through a membranous septal defect (arrow) into the right ventricle. (*Right*) Left anterior oblique projection, one and one-half seconds after injection. The right ventricle is now more densely opacified.

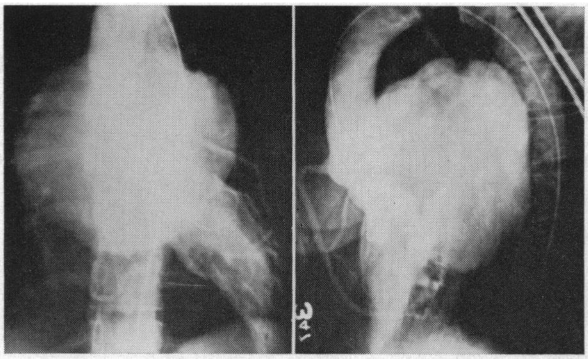

Figure 3.—Mitral insufficiency. (*Left*) Anteroposterior projection. (*Right*) Lateral projection. A polyethylene catheter with a "loop" on the end has been passed from the right femoral artery into the ascending aorta, through the aortic valve, and into the left ventricle. Following the injection of contrast agent, marked reflux into an enlarged left atrium is visible.

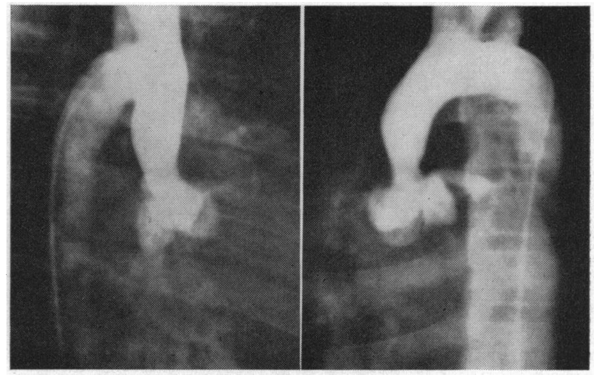

Figure 4.—Supravalvular aortic stenosis. (*Left*) Right anterior oblique projection. (*Right*) Left anterior oblique projection. A polyethylene catheter has been passed from the right femoral artery into the ascending aorta. With the injection of the contrast agent, a discrete zone of supravalvular stenosis is demonstrated. The left coronary artery is dilated, and arises just proximal to the zone of stenosis. Surgical correction of the supravalvular aortic stenosis was undertaken successfully.

injection in the left ventricle to show whether there is a left to right shunt at this level (Figure 2).

The knowledge that catheterization of the left atrium can be accomplished through the atrial septum in the presence of a patent foramen ovale which was of no functional significance prompted the recent development of the transseptal approach using needle puncture.[17] Originally designed to obtain left heart pressures and blood specimens, the method has recently been modified to permit passage of a catheter large enough for selective injection of the left cardiac chambers.

Direct puncture of the left atrium or of the left ventricle also permits selective deposition of contrast agent in these chambers. Although we have done left ventricular puncture, and continue to do it in patients in whom it provides the only route of access to the left ventricle when this must be studied, I consider it a more hazardous procedure than the catheter approach to the left ventricle.

Using percutaneous transfemoral puncture, a radiopaque or nonopaque polyethylene catheter may be passed from the femoral artery up to and around the aortic arch and through the aortic valve directly into the left ventricle. The loop catheter employed for coronary arteriography[3] has provided us with relatively easy access to the left ventricle in patients whose aortic valve is normal, and in whom the major problem is to show the degree of mitral insufficiency (Figure 3). A straight catheter is better in patients with aortic stenosis.

4. *The Aorta.* The role of thoracic aortography has been adeqately defined[2] in the study of coarctation of the aorta, patent ductus arteriosus, aortic stenosis and insufficiency, aortic aneurysm, aneurysm of a sinus of Valsalva, and many other lesions (Figure 4). Although the direct puncture of the ascending aorta was the first method of thoracic aortography to be described, such a blind approach is no longer required. Passage of a catheter from the radial or brachial artery following arteriotomy may properly be employed. Our own preference is for transfemoral percutaneous catheterization (Seldinger technique) and we would use the femoral artery (in preference to the brachial unless the aorta is obstructed).

Although translumbar aortography is a simple and widely used method for the study of the abdominal aorta, it is also a "blind" procedure, and it is my feeling that the hazard is slightly increased as compared with the transfemoral method. The catheter approach, with direct fluoroscopic vision for placement of the catheter, is preferable. Nevertheless, I have not hesitated to do translumbar aortography when circumstances have required its use.

5. *Coronary Arteriography.* In our experience, the impetus to the study of the coronary arterial bed in man is coming not alone from surgeons, as in so many other areas of vascular radiology, but from internists and cardiologists. Basically, the problem is to define the presence or absence of coronary disease in patients whose symptoms of chest pain and whose electrocardiographic findings cannot resolve this matter. Since this is a relatively large group, and since the management of these patients in terms of diet, exercise and anticoagulation must be based on a precise appraisal of the condition of their coronary bed, the increasing use of coronary arteriography must be anticipated.

For nonselective studies in clinical subjects, the loop catheter described by Bellman[3] has proved satisfactory (Figure 5). We have performed numerous studies in animals, varying the type and size of

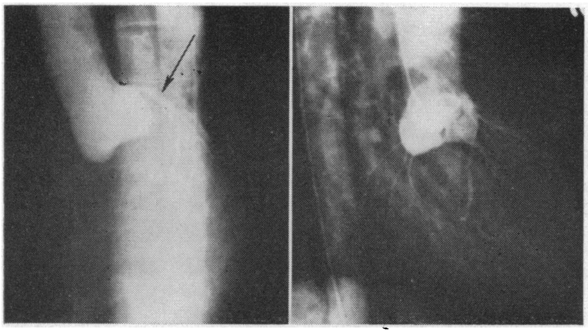

Figure 5.—Coronary arteriography. (*Left*) Left anterior oblique projection. (*Right*) Right anterior oblique projection. A loop catheter, passed from the right femoral artery into the ascending aorta, is in the supravalvular position. Following injection of the contrast agent, the left coronary artery is well visualized, with a discrete zone of narrowing just proximal to its bifurcation into the anterior descending and circumflex branches. The right coronary artery is well filled at this time, and is seen best in the right anterior oblique projection. The position of the loop catheter just above the aortic valve is clearly defined.

catheters, the size of the loop and the concentration of contrast agent. The loop appears to offer some advantages over the straight catheter, particularly in directing the contrast agent to the periphery of the aorta rather than centrally. It must be carefully placed directly above the valve cusps.

Coronary Catheterization

Our approach to selective coronary arteriography has concentrated on the development of a percutaneous transfemoral technique,[15] in contrast to the use of open surgical arterial exposure as advocated by Sones.[20]

In dogs, it proved difficult dependably to utilize a radiopaque polyethylene catheter with a fixed curve to catheterize both the right and left coronary arteries. This problem was resolved, however, by the use of two separate catheters, one for the right coronary artery and the other for the left coronary artery.[15] The right coronary catheter has a curve which corresponds to the aortic arch, but with the distal curve running anteriorly and to the right. The left coronary catheter also includes an aortic curve, but the tip curves to the left and posteriorly. Using the Seldinger technique, it is a matter of only a few minutes to introduce the second catheter when required. Thus, the left coronary artery may first be catheterized, the study performed and immediately thereafter the catheter withdrawn and replaced by a right coronary catheter. This has been done successfully many times in a series of animal studies, and recent experience with a small number of clinical subjects has been satisfactory (Figure 6, A and B). Selective coronary arteriography permits and requires the application of *ciné* techniques, since the fluoroscopic placement of the catheter must be fol-

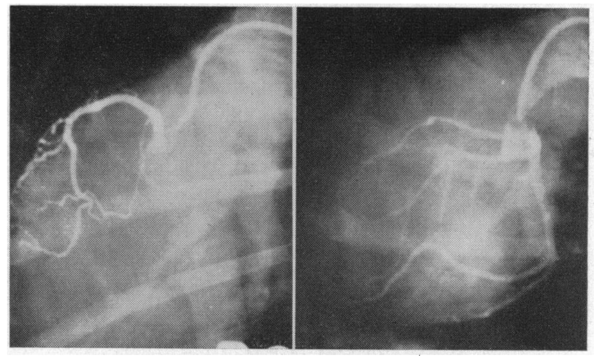

Figure 6A.—Percutaneous selective coronary arteriography. (*Left*) and (*Right*) Right and left coronary arteriograms in a dog. Specially designed catheters have been placed respectively in the right and left coronary arteries. Following the injection of 3 cc. of 76 per cent Renografin, there is excellent visualization of the proximal branches as well as of the distal ramifications.

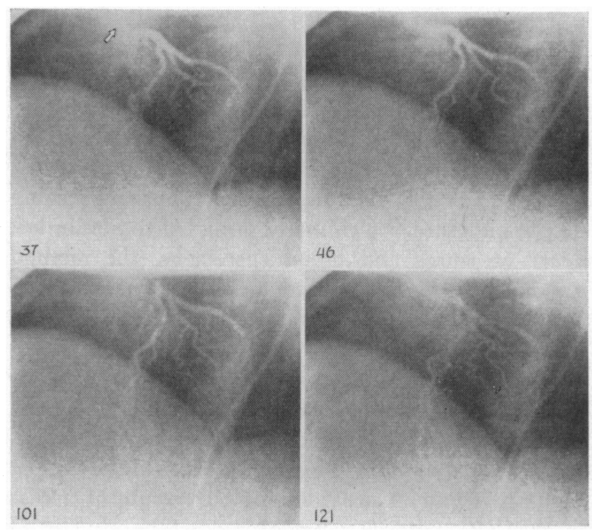

Figure 6B.—Selective left *ciné*-coronary arteriogram in a 59-year-old woman. Four frames have been selected from the sequence which was exposed at a framing rate of 48 per second for a four-second period. A 35 mm. Arriflex camera photographed the phosphor of a 9-inch image intensifier.

lowed by immediate x-ray recording and withdrawal of the catheter tip from the mouth of the coronary artery. Definition on the *ciné* strips is entirely satisfactory for this purpose.

6. *Cerebral Arteriography.* Percutaneous arterial puncture and injection are usually entirely satisfactory, and selective injection of the internal or external carotid artery can be accomplished by experienced hands with a high degree of success. Nevertheless it is true that percutaneous carotid artery puncture has produced dissection of the arterial wall, and this has prompted some investigators to advocate transcarotid catheter injection, using the Seldinger technique, so that the needle may be immediately withdrawn. Further advantages

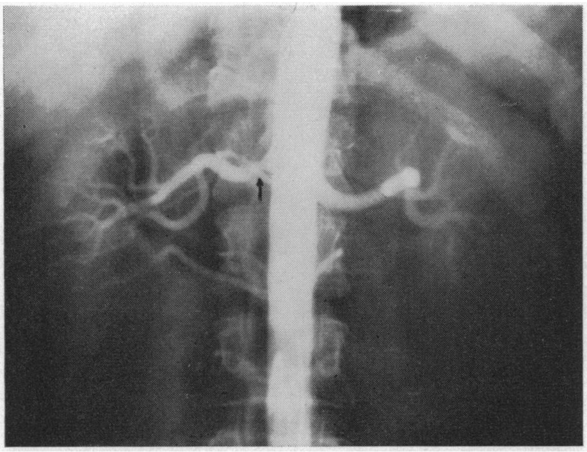

Figure 7.—Bilateral renal arteriography. A polyethylene catheter has been passed from the right femoral artery to the level of the second lumbar vertebral body. Following injection of the contrast agent, both renal arteries are well demonstrated, and there is evidence of narrowing of the right renal artery just distal to its origin.

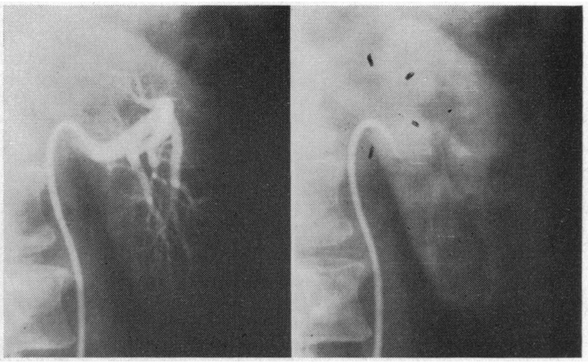

Figure 8.—Selective renal arteriography. (*Left*) Arterial phase. (*Right*) Nephrographic phase. A radiopaque polyethylene catheter has been placed in the left artery, and 5 cc. of 76 per cent Renografin injected. This demonstrates the left renal artery and its ventral and dorsal branches. In one area in the mesial portion of the upper pole of the left kidney, there is failure of filling of arterial branches. The nephrographic phase demonstrates a discrete radiolucent area, representing a renal cyst.

of catheter injection lie in the ease of moving the patient without fear that the catheter will be withdrawn from the artery (which may occur with the needle technique), and in the ability to pass the catheter either into the internal or external carotid artery. Thus, both systems may be studied in sequence with a single needle puncture but without superimposition of the external and internal carotid arterial beds.

When carotid arteriosclerosis is to be investigated, direct injection into the carotid artery is undesirable, since the entire artery must be visualized from its very origin. Injection into the aortic arch through a catheter inserted via the transfemoral route is then the procedure of choice.

Percutaneous needle puncture of the vertebral arteries is successful in experienced hands in about 80 per cent of cases. The vertebral arteries may also be visualized by catheterization from the radial or brachial arteries. Perhaps the simplest approach to the left vertebral artery is transfemoral percutaneous catheterization, since a straight polyethylene catheter can usually be passed quickly from the descending thoracic aorta into the left subclavian artery, and thence into the vertebral artery. In order to study the right vertebral artery from below, a stiff radiopaque polyethylene catheter of the Ödman type may be employed but it should be carefully shaped so as to enter the innominate and subsequently the right subclavian artery. This is, however, far more time-consuming than the left vertebral catheterization.

7. *Renal Angiography.* In the study of hypertension of renal vascular origin, bilateral renal arteriography is necessary, and in these circumstances a single, relatively large bore polyethylene catheter (PE No. 260) with an end hole and side holes may be inserted via the transfemoral route to the level of the second-third lumbar interspace, and 30 cc. of 76 per cent Renografin® injected (Figure 7). The renal arteries usually originate about the level of the first-second lumbar interspace, but there is sufficient reflux with a pressure injection to obtain an adequate bolus of the contrast agent at the mouth of the renal arteries. Moreover, this prevents flooding of the superior mesenteric and celiac arterial bed, and consequent superimposition of these vessels on the renal arteries.

When disease in one kidney is to be studied, the Ödman green radiopaque polyethylene catheter may be shaped with a bend which conforms to that of the renal artery take-off from the aorta and selectively catheterized (Figure 8). In such circumstances, an injection of 5 cc. of 60 per cent Renografin is usually adequate to obtain excellent opacification of the renal arterial bed and a good nephrographic stage. The curve should be directed posterolaterally, rather than anteriorly (as for the superior mesenteric artery), and the lordotic curve of the patient must be taken into account in shaping the catheter. The advantage of selective renal arteriography lies in the assurance that there will be no superimposed vessels to obscure the vascular pattern being studied. In addition, a small amount of contrast agent is used, and unnecessary perfusion of other arterial beds is avoided.

8. *Celiac Arteriography.* Celiac arteriography is useful in the study of the vascular beds of the pancreas, the liver and the spleen. The celiac artery may be selectively catheterized by use of an appropriate anterior curve of the distal end of the catheter.

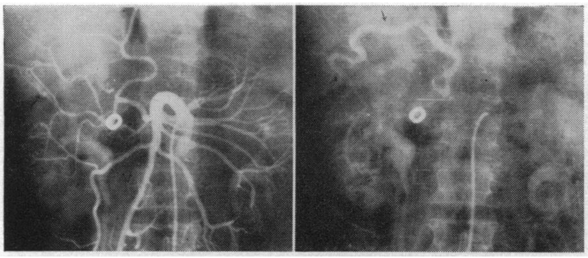

Figure 9.—Superior mesenteric arteriography. (*Left*) Film at one second. (*Right*) Film at five seconds. A radiopaque polyethylene catheter has been placed in the superior mesenteric artery, and with the injection of the contrast agent, there is excellent demonstration of the intestinal branches, the middle colic, right colic, and ileocolic branches. An abnormal arteriovenous communication is visible in the left panel (arrow). In the right panel, the vein which filled prematurely is identified as the right colic (arrows).

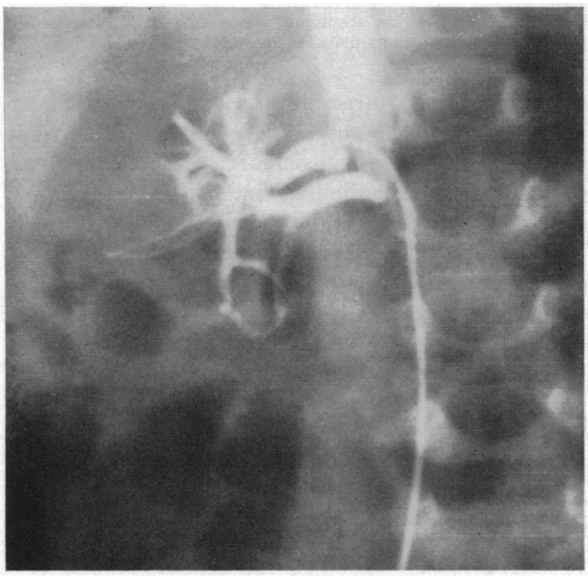

Figure 10.—Selective renal venography. A polyethylene catheter has been passed from the right femoral vein up through the inferior vena cava into the right renal vein. With retrograde injection, filling of two renal veins is demonstrated, and there is also partial filling of the inferior vena cava.

A relatively large volume of contrast agent may be injected slowly under low pressure. Serial filming is required. In order to define the anterior bend of the catheter when the vessel is catheterized, it is useful to carry out fluoroscopic examination with the patient in lateral projection. Simultaneous biplane studies, although desirable, are difficult to obtain because of the scatter produced in studying the abdominal region. Therefore, two injections are necessary if both anteroposterior and lateral views are to be obtained. In studying the problem of pancreatic carcinoma, celiac arteriography may demonstrate not only vessel displacement but also abnormal "tumor vessels" at times.

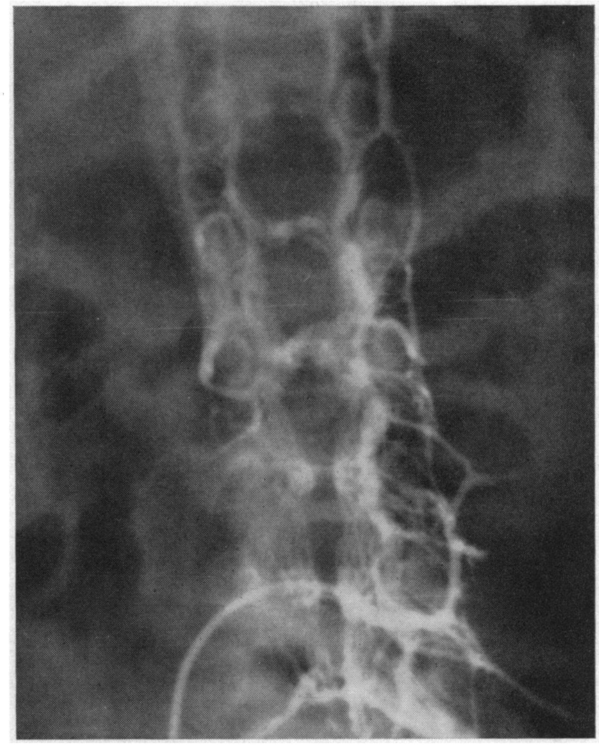

Figure 11.—Selective lumbar venography. The catheter has been passed into the inferior vena cava, and into a left lumbar vein. Following the injection of the contrast agent, the paravertebral plexuses and the ascending lumbar veins are well filled.

9. *Superior Mesenteric Arteriography.* The study of the superior mesenteric arterial bed has not as yet reached a point where its value can be assessed. We have undertaken to use this method in the evaluation of gastrointestinal bleeding of unknown origin (Figure 9), but have not had adequate experience as yet to indicate whether this will provide a useful ancillary method for defining the precise site of hemorrhage in patients with acute bleeding.

10. *Other Vascular Beds.* A number of other areas of vascular visualization may be mentioned briefly. *Inferior venacavography* is best performed by using the Seldinger technique and passing catheters into both femoral veins, with simultaneous injection through each catheter of a total of 40 cc. of 76 per cent Urografin®. The femoral veins may also be studied in this way. *Renal vein catheterization* is readily accomplished from the femoral vein if the catheter is bent to conform to the shape of the renal vein (Figure 10). Study of the renal vein is sometimes useful in cases of renal neoplasm or when renal vein thrombosis is suspected. *Lumbar vein catheterization* may provide an alternative route of demonstrating the azygos circulation, although this has not yet been adequately explored (Figure 11).

Subclavian arteriography via the transfemoral route may be very useful in the study of scalenus anticus syndrome or of thrombosis or aneurysm of the subclavian artery. *Femoral arteriography* may be undertaken either by direct needle injection, or, with better results in our hands, by percutaneous catheter injection. In the study of an occluded femoral artery, the contralateral vessel may be utilized as the avenue of entrance to the aortic bifurcation. The portal venous circulation is best studied by direct *splenoportography*, which also permits visualization of the splenic vein and of the communicating venous system in the presence of portal or splenic vein obstruction.

DISCUSSION

The radiographic study of the cardiovascular bed has developed within recent years into an important, specialized segment of diagnostic roentgenology. Techniques for studying selectively the arterial and venous segments of the vascular bed are being ever more widely utilized, and have opened many new fields of radiologic study. Obviously the scope of this paper does not permit exhaustive treatment of this subject—only emphasis of a few significant elements in the approach to angiography. Further investigation of the normal is required in visceral vascular beds before the adequate assessment of disease patterns will be accomplished. In other areas, the definition of the normal has already been largely accomplished.

In the controversy over whether roentgen recording of cardiovascular studies is best accomplished by serial large filming or *ciné* techniques, the proper emphasis is on the complementary qualities of the methods and the desirability of using both. In the study of shunts and valve motion, for example, the *ciné* technique has proved especially valuable in our hands; for the definition of fine morphologic detail, large film remains superior. When *ciné* techniques are employed, the biplane approach so well established in large filming is preferable.[1]

The importance of the principle of selectivity in cardiovascular study is that it permits the deposition of contrast agent precisely at the point to be studied, and diminishes the masking and distraction by opacified vessels outside the field of interest. There is relatively little dilution by circulating blood of the contrast agent, and therefore the total dose to which the organism is exposed may be significantly diminished.

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REFERENCES

1. Abrams, H. L.: An approach to biplane cineangiocardiography. III. Early clinical observations, Radiology, 73: 531, 1959.

2. Abrams, H. L., Editor: Angiography, Vol. 1. Little Brown & Company, Boston, Massachusetts, 1961.

3. Bellman, S., Frank, H. A., Lambert, P. B., Littman, D., and Williams, J. A.: Coronary arteriography. I. Differential opacification of the aortic stream by catheters of special design—experimental development, N.E.J.M., 262: 325, 1960.

4. Berberich, J., and Hirsch, S.: Die röntgenographische Darstellung der Arterien und Venen am Lebenden, München Klin. Wchnschrft., 49:2226, 1923.

5. Brockenbrough, E., and Braunwald, E.: Left ventricular angiocardiography and transseptal left heart catheterization, Amer. J. Card., 6:1062, 1960.

6. Castellanos, A., Pereiras, R., and Garcia, A.: La Angiocariographica Radio-opaca, Arch. Soc. Estu. Clin. Habana, 31:523, 1937.

7. Chavez, I., Dorbecker, N., and Celie, A.: Direct intracardiac angiography: Its diagnostic value, Amer. Heart J., 33:560, 1947.

8. Forssmann, W.: Ueber Kontrastdarstellung der Hohlen des Levenden Rechten Herzens und der Lungenschlagader, München. Med. Wchnschr., 78:489, 1931.

9. Jönsson, G., Broden, E., and Karnell, J.: Selective angiocardiography, Acta Radiol., 32:486, 1949.

10. Moniz, E., de Carvalho, L., and Lima, A.: Angiopneumographie, Presse Med., 53:996, 1931.

11. Moniz, E., Diaz., A., and Lima, A.: La radio-arteriographie et la topographie cranioencephalique, J. Radiol. et Electrol., 12:72, 1928.

12. Nuvoli, I.: Arteriografia dell' Aorta Toracica Mediante Puntura dell' Aorta Ascendente o del Ventricolo s. Policlinico (sez. prat.), 43:227, 1936.

13. Ödman, P.: The radio-opaque polyethylene catheter, Acta Radiol., 52:52, 1959.

14. Radner, S.: Thoracic aortography by catheterization from the radial artery, Acta. Radiol., 29:178, 1948.

15. Ricketts, H., and Abrams, H. L.: Percutaneous selective coronary arteriography. J.A.M.A. in press.

16. Robb, G. P., and Steinberg, I.: Visualization of the chambers of the heart, the pulmonary circulation and the great blood vessels in man, Amer. J. Roentgenol., 41:1, 1939.

17. Ross, J., Jr., Braunwald, E., and Morrow, A. G.: Left heart catheterization by the transseptal route. A description of the technic and its applications, Circ., 22:927, 1960.

18. Dos Santos, R., Lamas, A. C., and Caldas, P. J.: L'arteriographie des membres de l'aorte et de ses branches abdominales, Bull. Soc. Nat. Chir., 55:587, 1929.

19. Seldinger, S. I.: Catheter replacement of the needle in percutaneous arteriography, Acta. Radiol., 39:368, 1953.

20. Sones, F. M., Jr.: Personal communication.